Shuttle Imaging Radar-C: A System Integration and Test Perspective

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1. INTRODUCTION

The Shuttle Imaging Radar-C (SIR-C) is a synthetic aperture radar (SAR) designed to fly on the Space Shuttle as a payload instrument in the Shuttle Radar Laboratory (SRL). To fly together with SIR-C are the German/Italian X-band SAR (X-SAR) and the Data Processing Subsystem (DPS), built by the Applied Physics Laboratory of John Hopkins University. The first mission is scheduled in mid-April, 1994, for an 8-day duration, with one follow-up mission in planning. The instrument itself - its inheritance, mission profile, potential scientific advances, design and performance - has been published earlier[1,2]. Most notable of SIR-C design features from the science data acquisition viewpoint are:

- Dual frequency (L-band at 1250MHz and C-band at 5300MHz) and full polarization (HH, HV, VH, and VV; H for horizontal and V for vertical) data acquisition, providing complete polarimetric scattering information in two frequencies;
- Active phased array antenna, enabling antenna beam shaping and steering for flexibility in ground coverage and target pointing;
- Selectable signal bandwidth (10MHz and 20MHz) for different resolution and swath width;
- Multiple PRF (pulse repetition frequency) operation for resolving azimuth ambiguities[3], leading to improved signal to noise ratio (SNR) and image registration;
- Variable data window selection, for better targeting and compensating for Shuttle orbit drift;
- Elevation beam null operation, enabling the determination of antenna beam pointing for radiometric removal of antenna patterns;
- Built-in calibration sequences, providing engineering data for more quantitative assessment of instrument health during the mission and post-mission data calibration.

In addition to these "baseline" features, the present SIR-C design has incorporated some "experimental" features. These include

- Azimuth tracking for spotlight SAR operation at up to 33 azimuth pointing angles;
- ScanSAR operation for wider swath coverage with up to 4 different elevation angles;
- Interferometric along-track SAR operation (C-band VV polarization only);
- 40MHz signal bandwidth for the finest resolution available (data rate limited).

With these features in the design, SIR-C by itself is a demonstration of spaceborne radar technology, SAR technology in particular, accumulated over the past decade. Each of these features contributes to the complexity of SIR-C design, which in turn poses a significant challenge to the integration and test process by which the SIR-C instrument will be verified and its performance certified.

The paper is organized as follows. Section 2 presents some SIR-C features that were not elaborated or presented in the previous papers[1,2]. These special features, as will become clear later, have considerable impacts on the design of the electronic ground support equipment (EGSE). Section 3 describes the SIR-C electronics system level integration and test (I&T) process, with emphasis on the EGSE which supports the system level testing. As is true with any EGSE, the SIR-C EGSE is custom designed for the SIR-C instrument. The EGSE design features, therefore, will be presented in the context of SIR-C I&T. The design approach, however, is applicable to any radar I& 'J' program in general. Section 4 presents some of the latest test results and the instrument performance update. Section 5 is the conclusion.

2. SOME SIR-C INSTRUMENT FEATURES

The SIR-C flight instrument is shown in Figure 1, together with the EGSE under a generalized system Lest configuration. In this section, we present some features that were not elaborated or presented earlier.

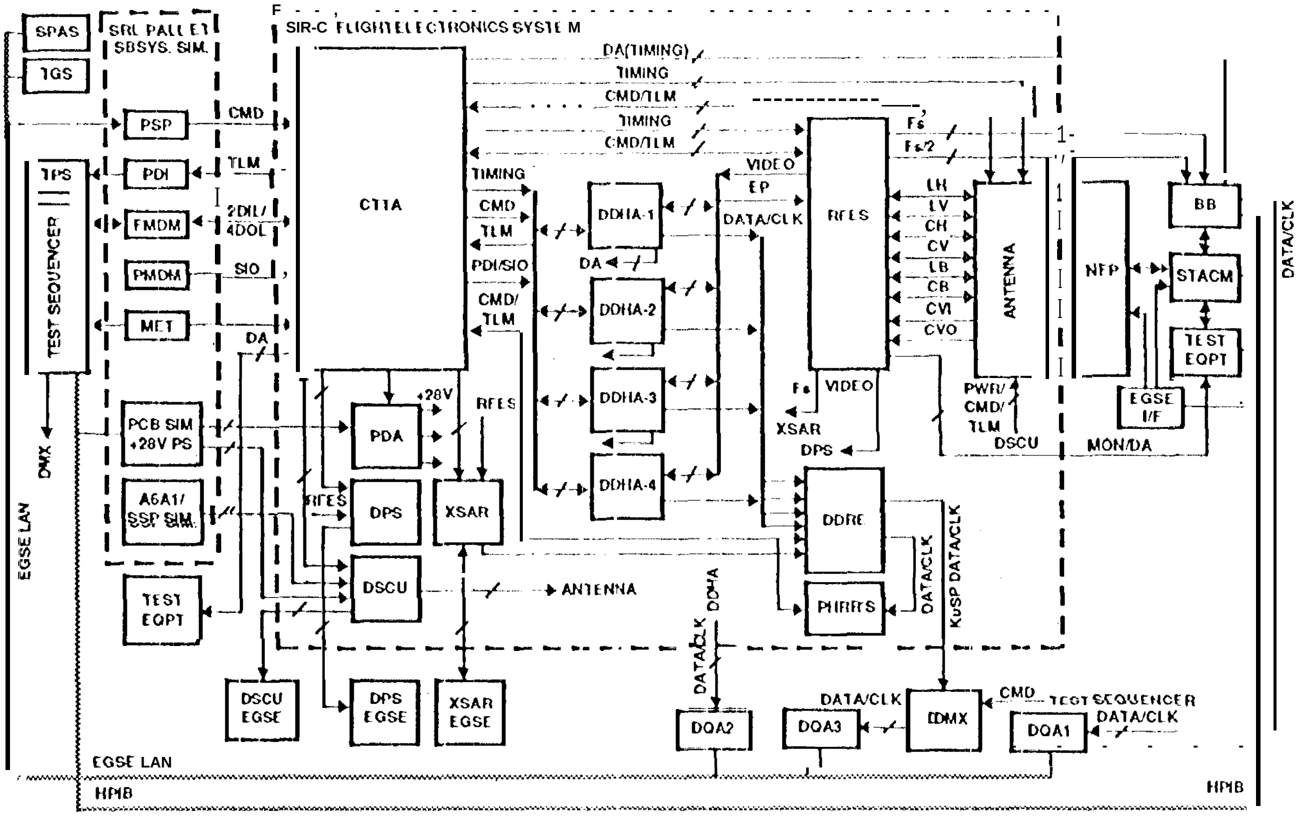
2.1. SIR-C Regular Datatake Sequence

A nominal SIR-C science datatake sequence consists of one-second timed events in which the SIR-C instrument assumes different configurations (or states). Referencing to the commanded datatake MET, these events take place in 5 successive phases. The pre-datatake phase is about 90secs before the commanded MET during which the SIR-C instrument is initialized and set up based on the commanded parameters. The start-up engineering datatake phase which lasts for 6secs begins at the commanded MET. During this 6-sec duration, the events are timed on the second and can be commanded to different options. One example: 1st second: receive noise only, 2nd second: multiple CW tone sweep, 3rd second: antenna LNA Panel BITE, 4th second: antenna HPA Panel BITE, 5th and 6th seconds: two PRF's different from that for the science datatake. After the start-up engineering phase, SIR-C commences the science data acquisition phase for a commanded duration. By the end of the science data acquisition, SIR-C enters the trailing engineering datatake for 6secs during which there are 2secs of different PRF's and 4secs of receive only noise. By the end of the trailing engineering datatake, SIR-C starts the post-datatake phase during which the subsystems are shut down according to the commanded instrument idle state. The 5 phases of a regular datatake are depicted in Fig. 2.

The data collected during the start-up phase and trailing phase are to be used for engineering purposes. The noise only data provides an estimate of system noise. The multiple CW tone sweep for 11 in-band frequencies provides an estimate of system transfer function. The data from LNA Panel BITE permits assessment of the health of the antenna LNA's (receive) on the panel basis. The data from the HPA Panel BITE provides the same for the antenna HPA's (transmit). (The HPA/LNA BITE operation will be elaborated shortly in the next section.) The data acquired at different PRF's over 2secs each in the start-up and trailing phases are to be used in conjunction with the data during the science datatake phase, a total of three different PRF's over the target, to resolve azimuth Doppler ambiguities[3].

2.2. Antenna BITE Sequence

The SIR-C antenna consists of two separate, but similar in design, antennas, one for L-band and the other for C-band. Each of the antennas is an active planar phased array, consisting of 18 panels that are fed through a corporate feed network. The L-band array has 18(elevation)×9(azimuth) radiation elements and C-band has 18(elevation)×18(azimuth). The radiation elements are dual-polarization (H and V) fed microstrip patches. For every radiation element, there are two sets of transmit/receive (T/R) modules,



SIR-C FLIGHT INSTRUMENT
CTTA: Command, **Timing, Telemetry Assembly**
DDHA: Digital Data **Handling Assembly**
DDRE: Digital Data Routing Electronics
DSCU: Deploy/Stow Control Unit
PDA: Power Distribution Assembly
PHRR: Payload High-Rate Recorder
RFES: Radio Frequency Electronics Subsystem

OTHER SHTTULE RADAR LAB.(SRL) INSTRMENTS
DPS: APL Data Processing Subsystem
X-SAR: X-Band Synthetic Aperture Radar

ELECTRONICS GROUND SUPPORT EQUIPMENT
BB: Bread-Board
DMX: Demultiplexer
DQA: Data Quality Analyzer
FMDM: Flexible Multiplexer/Demultiplexer Simulator
MET: Mission Elapse Time Clock
NFP: Near Field Probe
PCB: Power Control Box Simulator
PDi: Payload Data Interleave Simulator
PMDM: Payload Multiplexer/Demultiplexer Simulator
PSP: Playload Signal Processor Simulator
SPAS: System Performance Analysis Subsystem
SSP: Standard Switch Panel
STACM: System Test and Calibration Matrix
TGS: Table Generation Subsystem
TPS: Telemetry Processing Subsystem

Figure 1: **SIR-C** Instrument **and** EGSE block diagram with tile acronym list.

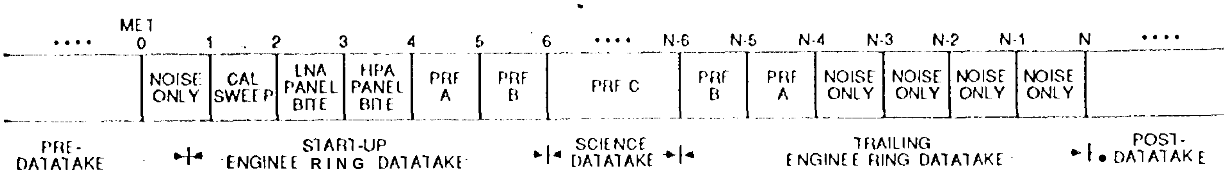


Figure 2: Different SIR-C instrument phases for a regular datatake sequence.

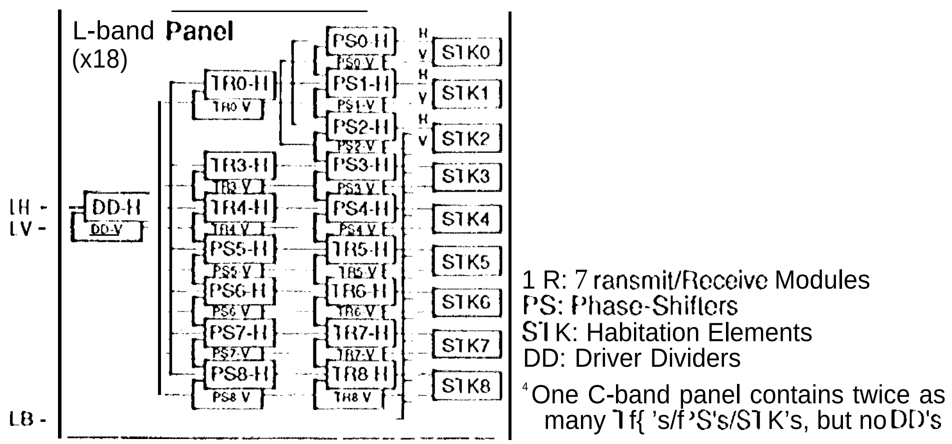


Figure 3: SIR-C L-band antenna panel schematic.

each of which consist of a high power amplifier (HPA) and a low noise amplifier (LNA). One set of the T/R's are dedicated to H-pol and the other set to V-pol. In addition, two sets of phase-shifters are also implemented, again for H-pol and V-pol respectively. The separate sets of T/R's and phase-shifters allow independent steering for the H-pol and V-pol beams. One special feature for the SIR-C antenna is the inclusion of RF built-in text, equipment (BITE). This multi-port coupler taps signals from each T/R, enabling the evaluation of the HPA's and phase shifters in the antenna transmit path. It also allows injection of signals from the RFES into the antenna receive path to evaluate the LNA's and the phase shifters. The schematic of one L-band antenna panel with the T/R's, phase snifters and BITE are shown in Fig. 3.

To utilize the antenna BITE, the SIR-C instrument implements one special type of data.take sequence for engineering purpose only. There are 6 options in this BITE datatake sequence.

1. HPA Panel BITE to receiver: The antenna is turned on one panel at a time in successive order. The RFES drive signs] traverses through the panel HPA's and phase snifters through the LH and/or LV ports. The BITE-coupled signal returns to the RFES through the LB port. The signal is then routed through the RFES receivers and is digitized and recorded as high rate data.

2. HPA Pant] BITE to power monitor: Same as the HPA Panel BITE except that the signal returned to the RFES LB port is routed to the power monitor in the RFES and the measured power delivered as part, of the telemetry.

3. LNA Panel BITE: The RFES delivers a CW signal to the antenna LB port on the panel basis. The CW signal is coupled through BITE to the phase shifters and the LNA's, then back to the RFES through the LH anti/or LV port. The signal then goes through the RFES receivers and is digitized and recorded as high rate data.

4. HPA T/R BITE to receiver: Same as the HPA Panel BITE to receiver but the antenna is being turned on one T/R at a time.

5. HPA T/R BITE to power monitor: same as the HPA Panel BITE to power monitor but the antenna is being turned on one T/R at a time.

6. LNA T/R BITE: Same as the LNA Panel BITE but the antenna is being turned on one T/R at a time.

For the Panel BITE, the 18 panels of the antenna for each frequency band are turned on one panel at a time successively, with a dwell time of 64 pulses. The entire array can be tested within 1 sec. For the T/R BITE, each T/R on each panel is turned on in succession for 16 pulses. It takes 3 secs to completely test the entire array. Note that in the regular datatake, there are also optional 1 sec of HPA Panel BITE and 1 sec of LNA Panel BITE in the start-up engineering datatake. The implementation of the HPA Panel BITE is the same as the HPA Panel BITE to receiver in the special BITE sequence, while the LNA Panel BITE is the same as that in the special BITE sequence. In addition, during the science datatake phase, the HPA power monitor in the RFES is used to measure full array transmit power as part of the telemetry, and the CW signal can be routed to either the full array of LNA's on the antenna, or to the RFES receivers for digitization as high rate to monitor receive gain.

2.3. Antenna Beam Null Operation

The SIR-C instrument provides an optional beam null operation. As the SIR-C antenna is a phased array, reversing the phase shifters 180° in half of the array elements in elevation produces an elevation pattern that has a notch at the boresight of the normal pattern when the phase shifters are not reversed. The intent is to use the null beam data to estimate the elevation angle where the null occurs. Assuming that the null angle is the same as the boresight angle of the normal beam, the range antenna pattern can be removed more accurately. For the SIR-C implementation, the null beam operation occurs once every second for one interpulse duration on receive only (not transmit).

2.4. Interferometry Mode Operation

This special C-band VV only feature allows SIR-C to radiate from the entire C-band array but receive the echoes from the forward one-third and aft one-third of the array separately. These two signals are fed to two different receiver channels. This operation enables SIR-C to operate as an along-track interferometer.

2.5. Extended Swath Operations

There are three implementations in the SIR-C design to extend the swath coverage beyond the instrument data rate constraint, with a different penalty for each of the implementations.

1. Use a pair of DDHA's to acquire data over the illuminated swath. The 1st DDHA captures the first half of the echo and the second DDHA captures the immediate second half of the echo. This extended swath operation limits the data acquisition to 2 polarizations for a single frequency out of possible 4 polarizations, or 1 polarization for each of the two frequencies.

2. Use two PHRR's to record data, which doubles the data rate throughput. The SIR-C DDRE, instead of multiplexing 4 DDHA's parallel data to 1 serial data to one PHRR in regular operation, multiplexes 2 DDHA's parallel data to 1 serial data to each of the PHRR pair. For 4 DDHA's, two PHRR's will record data simultaneously. Additional resources are required during mission operation and data processing.

3. Use ScanSAR operation in which the antenna beam is scanned in elevation for a maximum of 4 angles with minimum dwell time of 30 msecs. The data from each angle are then processed and mosaicked to form a wider swath. This operation complicates the mission planning and requires additional data processing. The SIR-C implementation limits this operation to single polarization transmit operations only.

2.6. Azimuth Tracking Operation

This implementation is also known as the "spotlight" SAR operation during which the antenna beam is steered in azimuth to aim at a fixed target on the ground as the Shuttle travels by. This effectively increases the illumination time of the target, or increases the synthetic aperture length, leading to finer azimuth resolution. The SIR-C design allows the antenna beam to be steered in azimuth in rapid succession, with minimum dwell time of 30msecs. Up to 33 azimuth angles can be commanded, and the steering direction can be either forward or reverse. Again, SIR-C is limited to single polarization transmit only for this mode of operation and the processing is considerably more complicated than the nominal SAR operation.

2.7. 40MHz Operation

The SIR-C DDHA's digitize the echo at a constant rate of 45MHz. As such, 40MHz signal bandwidth violates the Nyquist criterion. To effectively increase the digitization rate to 90MHz, two DDHA's are used as a pair. The first DDHA digitizes the signal from the rising edge of the digitization clock while the second DDHA digitizes it from the falling edge of the clock. Thus the two DDHA's digitize the same signal but providing alternate samples. When the two data sets are interleaved, the echo is effectively being digitized at 90MHz. As two DDHA's are needed to digitize one signal, the receive channels are limited to two.

3. SYSTEM ELECTRONICS INTEGRATION AND TEST

The SIR-C integration and test process can be divided into three phases: subassembly test, subsystem integration and test (I&T), and system integration and test. The definition boundary between subsystem I&T and system I&T is based on the flight hardware in the test configuration. As long as the flight hardware available for testing can form a functioning radar, although not yet the complete SIR-C, the integration of the hardware pieces to form that functioning entity and the ensuing test are considered as system level.

The SIR-C I&T process is dictated by two factors: (i) the subassembly fabrication and subsystem integration and test schedule, and (ii) the decision to proceed with system level integration and test even if the "system" consists of only partial SIR-C hardware. The second factor enables uncovering the subsystem interface problems at the earliest time possible. It also provides contingency in case of schedule change or project de-scoping that a fully tested and minimally functioning "system" will be available. However, as a result of this decision, the three phases of I&T activities became interleaved and dependent on each other. This complicated the I&T process considerably, as each phase of I&T activities shared the same set of resources, namely, workforce and EGSE. As such, it required a flexible and robust EGSE to cope with this dynamic process.

3.1. EGSE Hardware Functional Description

The SIR-C EGSE for system level testing was designed and implemented using primarily existing subsystem test equipment within the SIR-C project. The SIR-C EGSE is shown in Fig. 1 with the flight instrument. The hardware can be classified into the following categories:

1. SIR-C bread-boards (BB): The bread-boards were built in the early phase of SIR-C project to verify SIR-C design before production. For the system level test, the RFES bread-board and the DDHA bread-board were modified and re-configured. The modified BB effectively becomes another radar without antenna with various SIR-C signals available as test stimuli. It also performs as a coherent receiver with comparable bandwidths to capture and digitize the SIR-C transmit signals. Interfaces were built to allow computer control of the RFES BB parameters. During the test, the BB and the flight instrument operate in a complimentary manner. The BB generates chirps to inject into the SIR-C receivers when SIR-C is in receive. The generation of the chirps is coherent with the SIR-C flight STALO and synchronous with the flight PRF, with adjustable delay within interpulse interval. The BB thus behaves as an echo simulator, simulating a point target return of adjustable delay. When SIR-C is in transmit, the BB is used as a coherent receiver whose reference base frequency

is provided by the flight instrument. The chirps transmitted from the flight instrument can then be acquired in digital form for quantitative analysis. This configuration results in an EGSE that is completely coherent and synchronous with the flight instrument.

2. Shuttle interface simulators: The simulators were built based on the original drawings of the Shuttle pallet subsystem to which the SIR-C flight instrument will be interfaced in the SRL. During testing, these simulators interface directly with SIR-C while the EGSE in turn interfaces to the simulators. The simulators and their functions are:

   (a) Payload Signal Processor (PSP): Receives SIR-C commands from EGSE and delivers commands to SIR-C flight instrument.

   (b) Payload Data Interleaver (PDI): Receives SIR-C telemetry from SIR-C flight instrument and delivers to EGSE.

   (c) Power Control Box (PCB): Simulates pallet power and controls bus power to SIR-C flight subsystems.

   (d) Flexible Multiplexer/Demultiplexer (FMDM): Receives backup commands from EGSE and -ables SIR-C transmit in backup operation.

   (e) Mission Elapse Time (MET) clock: provides standard time reference for the CTTA in its initialization. The MET clock is usually set at local time during the test. The EGSE also inquires and uses the time as reference for EGSE control.

   (f) Standard Switch Panel (SSP)/A6A1: this is used only to control the X-SAR tilt operation.

   (g) Payload Multiplexer/Demultiplexer (PMDM): Simulates serial **I/O (SIO)** orbiter attitude and state vector,

3. Custom-built equipment: Of the EGSE, the most important in this category are the system test and calibration) matrix (STACM), the data quality analyzer (DQA), and the near field probe (NFP).

   (a) System Test and Calibration Matrix (STACM): This a multi-port device whose main function is signal routing and signal level adjustment. There are two STACM's: one for L-band and the other for C-band. The STACM's permit several test signal sources to be selectively injected to the flight instrument, and allows the transmit chirps from various channels of the flight instrument to be routed to various test instruments. The signal sources can be chirps from BB, CW, AM, or noise signals from synthesizers. The STACM's have precision attenuators to fine tune the injected signal for optimal test level. Another function of the STACM's is to provide monitor ports to monitor the signal in route by power meters or spectrum analyzers. The signal routing paths and attenuator settings are under computer control.

   (b) Data Quality Analyzer (DQA): The custom-built equipment is designed to capture the SIR-C digitized high rate data. The DQA detects the headers in the high rate data and can start acquiring the data based on selected attributes in the header. One attribute that is used most frequently is the MET in the header. The DQA also performs data tracking, using the pseudo-noise code in the header to ensure good data transfer, and data conversion to accommodate different data format from the DDHA 's. A Macintosh computer serves as the interface between DQA and the rest of the EGSE. The combination of DQA/Mac allows acquisition of the high rate data starting from a pre-determined MET for a desired amount of data not exceeding the DQA buffer size.

   (c) Near Field Probe (NFP): The near field probe is used only when the antenna panel is under test. It is a surface probe which permits detection of surface current on each radiation element of the antenna when the antenna is radiating. It also allows the injection of test signals into the antenna panel when the panel is in receive.

4. Commercial instruments: these are the standard instruments found in any microwave laboratory, e.g. power meters, spectrum analyzers, oscilloscopes, logic analyzers. Most of the instruments are equipped with the general purpose interface bus (GPIB) control.

5. Computers: There are 4 computers, in addition to the Mac's used by the DQA's, in the EGSE. All the computers are networked by EtherNet.

   (a) Test Sequencer: This is the central computer which coordinates the test activities. This computer interprets the test sequences, and based on the content of the sequence, sends commands to set up EGSE and to acquire data from the selected instruments. It also sends SIR-C commands to the flight instrument via PSI]. Once the test data are acquired, the Test Sequencer creates a file, called preamble, which contains all the test attributes, and adds the preamble to the data file. The data files are then delivered to the System Performance Analysis Subsystem.

   (b) System Performance Analysis Subsystem (SPAS): This computer receives data delivered from the Test Sequencer, extracts the preambles, and inserts the preambles into a database. The information in the preambles, thus in the database, allows on-line inquiry of the data attributes for file search and compilation. The data analysis software resides in this computer. The software package includes radar signal analysis and processing software. It also contains utility programs for plotting.

   (c) Telemetry Processing Subsystem (TPS): This subsystem consists of two major modules, the telemetry input console (TIC) and telemetry output console (TOC). The TIC is responsible for receiving and archiving; the SIR-C telemetry delivered from flight instrument via the PDI. It also decommutates the. telemetry and converts raw data into engineering units. The TOC is responsible for providing multi-console graphic telemetry displays. The color-coded displays allow the user to discern anomalies. The TPS can also play back archived telemetry.

   (d) Table Generation Subsystem (TGS): This computer is used to support the generation of various tables to be used by the test sequencer. There are three tables: control table, command table, and configuration table. The TGS contains the forms for each of the tables. The generation and usage of these tables will be described in the next sec. tion.

3.2. EGSE Software Functional Description

The software in the EGSE is as crucial to the EGSE operation as its hardware counterpart. Two major pieces of EGSE software, the test control software, or test software (TSW) for short, and the analysis software (ASW) were designed and implemented.

The EGSE TSW is a table-driven test sequencing software that resides in the Test Sequencer. Two layers of tables consisting of a total of 3 tables are prepared before the test. These tables were implemented in the TGS using commercial spread-sheet software.

1. Control Table: This is the top layer table which dictates the test sequences. In each of the sequences, the content in the table prescribes the activities in that sequence, which may include sending SIR-C command to the flight instrument and sending commands to set up various EGSE instruments. If sending a SIR-C command is required, the Control Table refers to a table in the second layer, the Command Table. If the EGSE setup involves the STACM's, then another second-layer table, the Configuration Table, is referenced. If the commands are to be sent to commercial instruments, then

the entry for that instrument will contain the exact GPIB command to send. In addition to prescribing the EGSE commanding activities, the Control Table also contains relative time information for the TSW to activate the instrument at a prescribed time. Since the **SIR-C** instrument states can be referenced to the time when the datatake will start, the TSW uses the same time to control the EGSE. As a result, the entire EGSE is synchronized in time with the flight instrument state. That the EGSE is capable of acquiring data in any SIR-C state.s is critical to the. EGSE design, given the fact that the SIR-C state changes within a datatake (Sec. 2.1).

2. Command Table: This is the second-layer table which is referenced by the Control Table whenever there is a need to send a SIR-C command to the flight instrument. The Command Table contains all the 512-bit SIR-C commands to be used for a test session. The generation of this table involves 3 steps. The user first prepares a user entry table whose form partitions the 512-bit command into self-explanatory fields. Once the user-entry table is completed, the second table is automatically generated where each field is checked for its limits and inter-dependency to other fields. As a result, the second, verified table is devoid of human errors. This table, still in user readable form, is included in the test procedure for reference and archive. At the same time, the verified table is converted automatically into 512-bit form as the input to the TSW.

3. Configuration Table: This is the other second-layer table which is referenced by the Control Table whenever the STACM's are to be commanded. (This is actually two tables, one for L-band and one for C- band.) The Configuration Table contains every parameter needed for controlling the STACM's. Again, the user prepares the user-entry table and from which a binary table is automatically generated to be used by the TSW. As there are only limited number of STACM combinations, the same Configuration Table can be used for more than one test.

Since all the EGSE setups are prescribed by tables, and the TSW uses these tables as inputs, the major function of the TSW is to perform table interpretation and, based on the interpretation, to coordinate and execute the activities in the Control Table. This enables the design of TSW to be sufficiently generic while leaving most of the detailed test design activity in the tables. This offers three major advantages. First the TSW remains relatively stable throughout the I&T process. Second, the tables themselves leave traceable records for the executed tests. Third, the TSW allows selecting a portion of the test sequences to be executed, providing the flexibility in tailoring the test duration to the allocated time.

The second major piece of EGSE software, the analysis software (ASW), resides in the SPAS. The test data., the High-rate data in particular, acquired during the test are delivered to the SPAS by the Test Sequencer. As the TSW in the Test Sequencer is responsible for controlling the test activities, it has the detailed information on the test setup. This information is generated by the TSW as a parameter file, the preamble, and attached to the raw test data before delivery to the SPAS. An integral part of the ASW in the SPAS is the commercial database software that extracts the preamble from the delivered data and converts it into the database. This database then provides a test data catalog which allows on-screen enquiry of the test data based on test attributes. Another integral part of the ASW is the radar signal analysis and processing software package which allows the processing and analysis of the test data. This package includes software to process and analyze chirps, CW signals and noise. Some of the programs directly interact with the database to perform massive data processing. It also contains special software to perform data calibration and antenna pattern calculation and evaluation. The results to be presented in the next section are performed by the ASW in the SPAS.

	HPA T/R BITE				LNA T/R BITE				
	H-pol		V-pol		H-pol		V-pol		
Stk	AA	$\Delta\phi$	AA	$\Delta\phi$	AA	$\Delta\phi$	AA	$\Delta\phi$	Exp.$\Delta\phi$
2	-2.0	-40"	- 0.5	- 40	0.7"	"- 42	- 0.7	- 44	-45.0
3	-0.2	- 82	- 0 . 4	- 58	i.o	- - 6 ?	0:6	-74	-67.5
4	1.9	- 111	-3.5	. 82	0.7	- 85	--0.8"	-105	-90.0
5	-- 0.4	- 118	-0.'2	- 106	0.4-	- 107	0.0	- 116	-112.5
6	- 0.3	- 138	0.1	- 126	0 . 2	- 127	0.2	-133	- 135.0
7	--0.2	- 158	-0.1	- 149	- 0.5	- "150	0.1	- 157	- 157.5
8	- 0.8	- 181	-0.8	- 174	0.8	-174	0.2	- 181	- 180.0

Table 1: HPA and LNA T/R Ill'J'I'; results from one L-band antenna pane]. The amplitude deviation (AA) in dB and phase deviation ($\Delta\phi$) in degrees for the elevation radiation elements (sticks) are the between the 5° elevation beam and the 0° broadside beam.

4. LATEST RESULTS

As of the writing of this paper, SIR-C is at the peak of the system integration and test process. The flexibility of the EGSE **has** proven to be critical to maintain the tight schedule. in the process, a large quantity of test data has been acquired. As the test data arc being analyzed, the results are incorporated into the system model to update the system performance. In this section, we select some test results which relate to Silt-C special design feature.s that may have important implications to future system design, followed by the latest system performance update.

4.1 Test Results

Three test results, each of which is related to the SIR-C special features described earlier, are presented in this section. The first is the results from antenna HPA and LNA T/R BITE (%x. '2.'2). The antenna was commanded to form beams at, two different elevation angles, 00 at broadside and 5° respectively. The HPA T/R BITE to receiver and the LNA T/R BITE sequences were executed for each angle. Using the 0° data as the reference, the deviation of the 5° data in amplitude and phase as estimated from the test data is presented in '1'able 1 for the HPA and LNA T/R BITE. The tlleore.tics] amplitude deviation is 0dB and phase deviation is as shown in the table. The results show that RF BITE can be used as a tool to monitor the health of the T/R's and the values of the phase-shifters during the mission. The test results also indicate that the data can be used to calculate the actual antenna pattern during; the mission.

The second test result to be presented is the beam null operation (Sec. 2.3). Figure 4 shows two LH antenna elevation patterns calculated from the test data. The first is the transmit pattern, or the non-null pattern and the second is the receive pattern, or the null pattern. The null pattern is generated once every second for one interpulse interval during receive if the null option is commanded on. Note that the notch in the null pattern occurs at the boresight of the non-null pattern.

The third test result is the 40MHz operation (Sec. 2?.7). Figure 5 shows the chirp spectrum and the compressed result. A test 40MHz chirp was injected into the SIR-C receivers and the signal was digitized by two DDHA's, one digitizing at the rising edge of the digitization clock and the other the falling edge. The digitized data from the two DDHA's were interleaved. The compressed chirp complies with the system requirements for resolution and sidelobes.

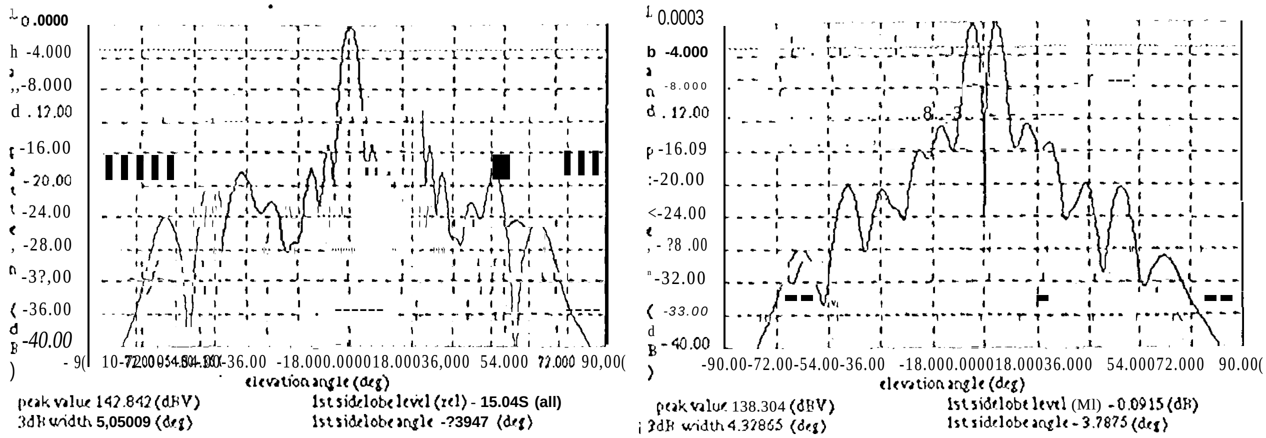


Figure 4: SIR-C antenna 1,11 non-null transmit elevation pattern vs. null receive elevation pattern

4.2. SIR-C Performance Update

The SIR-C system performance is being updated as the new test results are available.. The figure of merit for system performance presented in this section is the noise equivalent σ_0 ($NE\sigma_0$). The $NE\sigma_0$ is the differential scattering cross-section σ_0 of a homogeneous target on the ground whose echo level is equal to the instrument internal noise level. Thus the $NE\sigma_0$ specifies the sensitivity of the instrument such that only targets with higher σ_0 can be detected. Figures 6(a) and 6(b) are the $NE\sigma_0$ of the SIR-C L-band and C-band instruments respectively. The set of curves are related to different beam widths produced by the SIR-C antenna by controlling the phase-shifters, Beamwidth 1 being the narrowest beam, thus having the highest directivity, and Beamwidth 8 being the broadest beam. Each curve ends when the ambiguities exceed the - 20dB requirements.

5. CONCLUSION

In this paper, we first described some of the SIR-C features that have not been presented or elaborated in detail earlier. With all these design features, SIR-C itself is a demonstration of spaceborne SAR technology. The complexity of SIR-C poses a formidable challenge in its integration and test. The SIR-C EGSE presented in this paper is equally, if not more, complex than its flight counterpart. The flexibility and robustness in the EGSE design anticipate the dynamic and complex nature of SIR-C I&T process. The

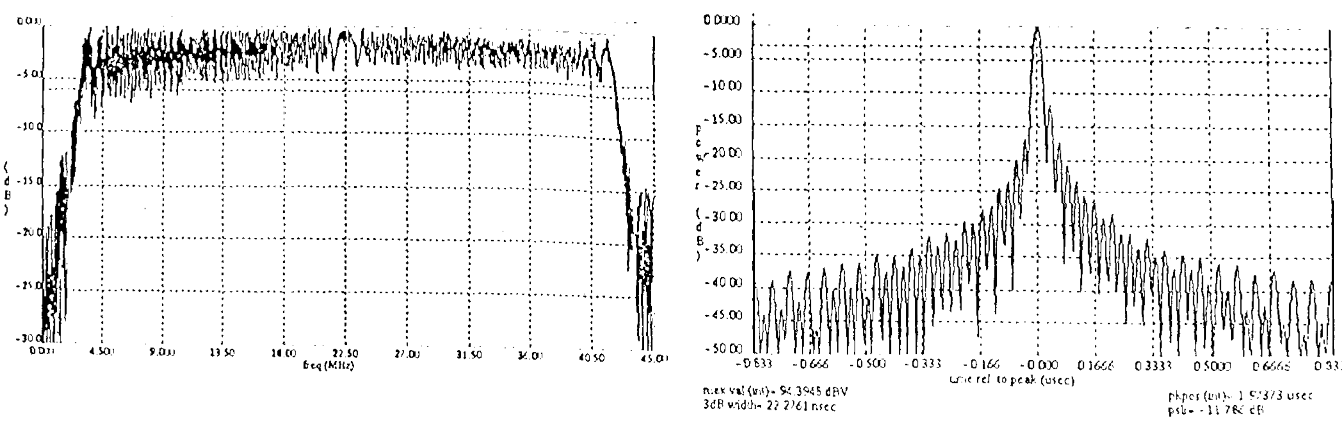


Figure 5: SIR-C 40MHz chirp compression verifying the 40MHz operation.

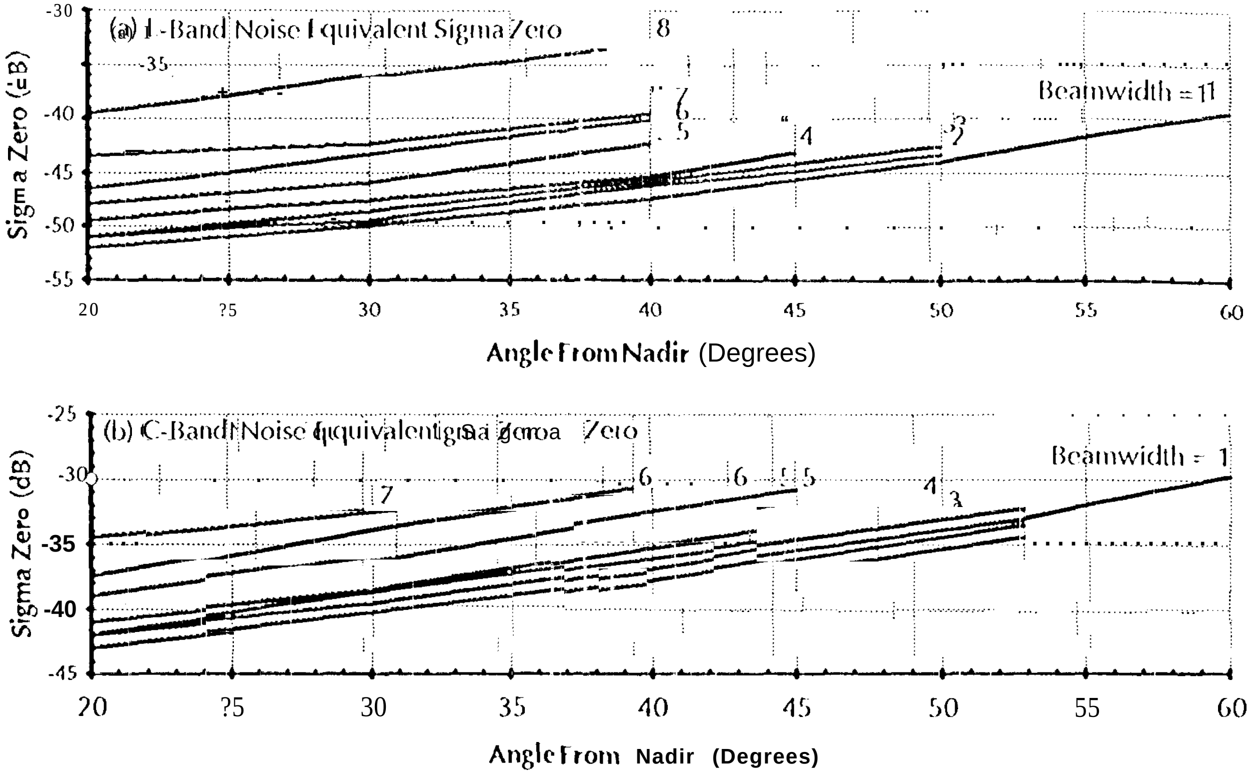


Figure 6: SIR-C system performance over different beamwidths and look angle in terms of noise equivalent σ_0: (a) L-band and (b) C-band.

mostly automated test sequencing improves the throughput of the test data acquisition, minimizes human errors, and shortens the test time. The integrated end-to-end design, from test definition to test sequencing, data acquisition, and data analysis, has proven to be critical throughout the still on-going I&T.

6. ACKNOWLEDGEMENTS

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